DC Machines

Stator (Field)
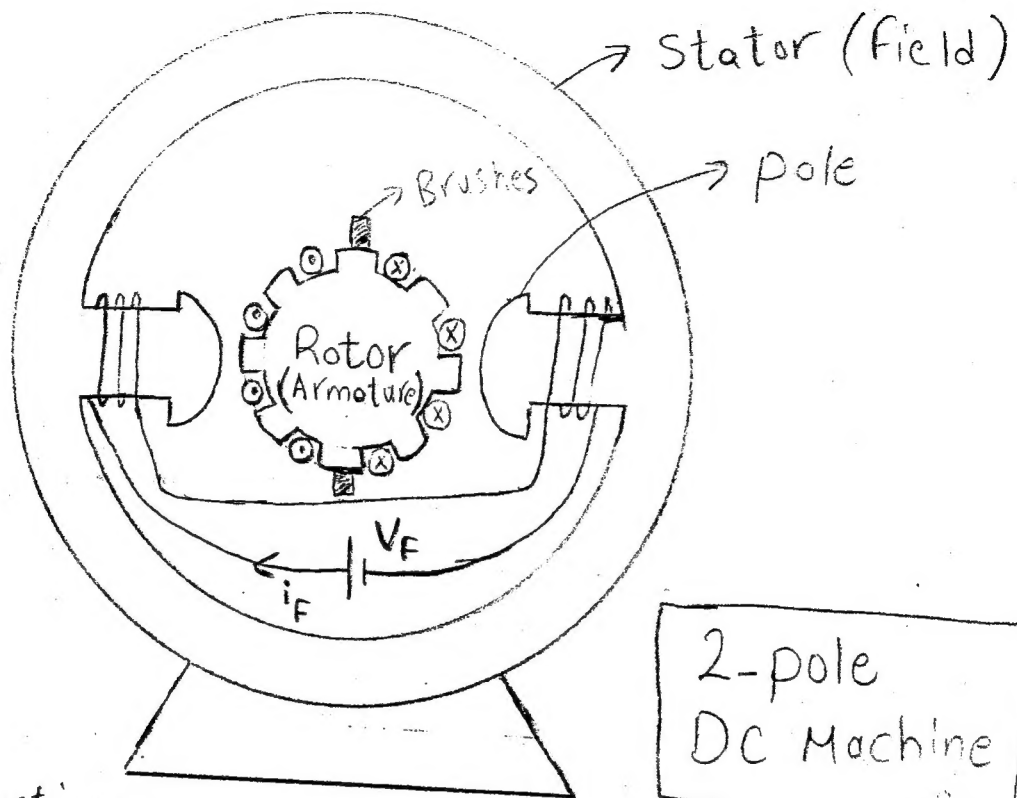
Pole

Brushes

Rotor (Armature)
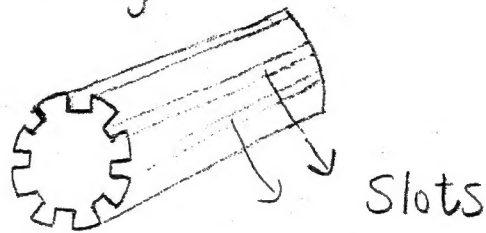
V_F

i_F

2-pole DC Machine

Construction

① Stator

- Carries the field winding (exciter)
- Field winding is connected to DC voltage source
- Field winding produces the magnetic flux.

② Rotor

- Carries armature winding
- Rotor has a cylindrical shape with slots
- The Conductors are placed in these slots.
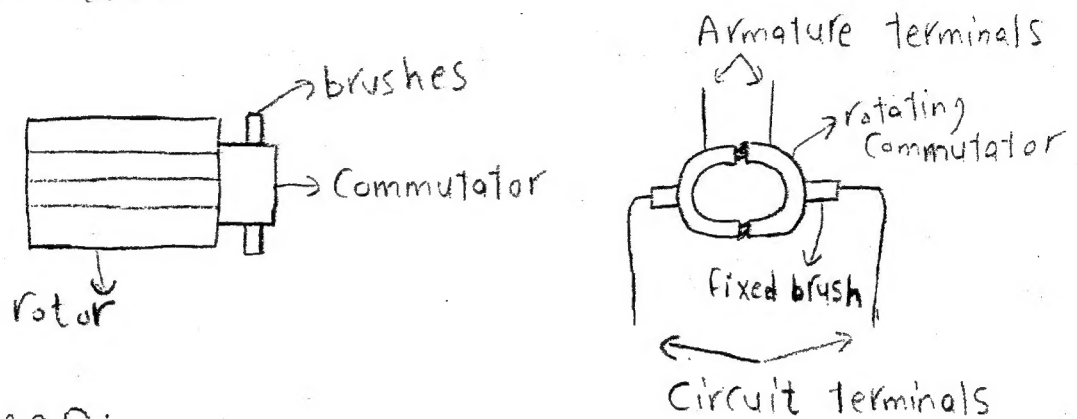- e.m.f is induced on the terminals of armature winding.

Slots

- Rotor is laminated to reduce eddy losses.

③ Commutator

* It's a copper cylinder divided into isolated segments
* It's connected to armature winding terminals
* It's a rotating part.

④ Carbon brushes

- They are fixed Contacts
- They are in direct Contact with the Commutator

⑤ Air gap:

- It's the clearance between Stator and rotor

Notes

ⓐ Commutator is used to
  → Convert Ac Voltage to DC Voltage in Case of DC genartor
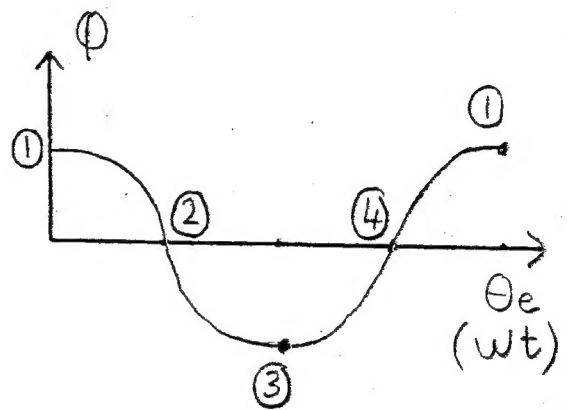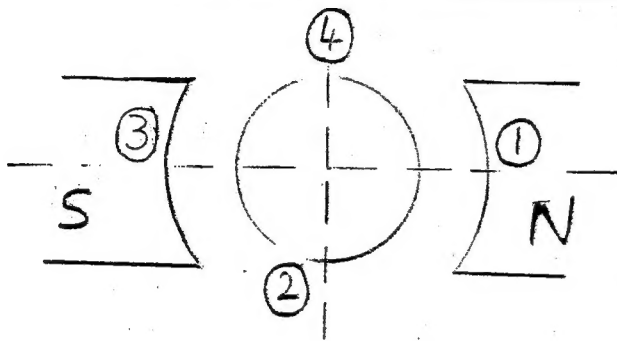 → produce unidirectional torque in DC motor

ⓑ The horizontal axis is Called pole axis, The Vertical axis is Called interpole axis.

Relation between θ_e, θ_m

$\theta_e = \omega t$; ω is electrical angular frequency

$\theta_m = \omega_m t$; ω_m is mechanical angular frequency
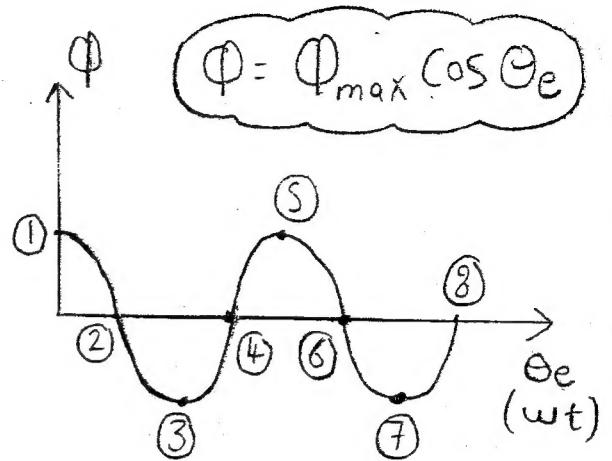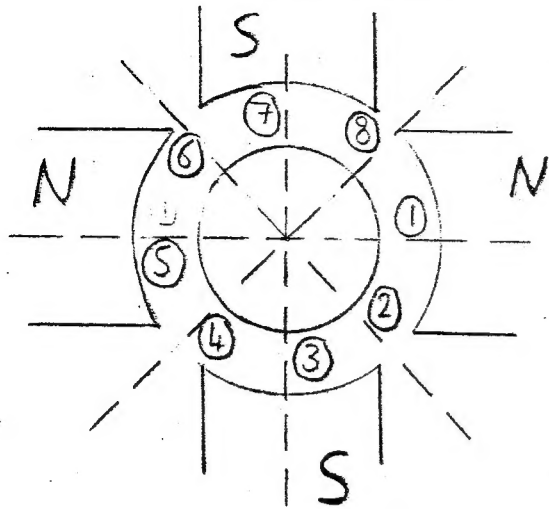
For 2 poles ($P = 1$)   ← no. of pole pairs

$\underline{① \rightarrow ②}$ $\theta_m = 90°$ $\theta_e = 90°$

$\underline{② \rightarrow ③}$ $\theta_m = 90$ $\theta_e = 90$

$$\boxed{\therefore \theta_m = \theta_e}$$

For 2 poles

For 4 poles $(p = 2)$

$$\phi = \phi_{max} \cos \theta_e$$

$$①→② \qquad \theta_m = 45 \qquad \text{but} \quad \theta_e = 90$$
$$②→③ \qquad \theta_m = 45 \qquad \text{but} \quad \theta_e = 90$$

$$\boxed{\therefore \theta_e = 2\theta_m}$$

∴ For (p) poles

$$\boxed{\theta_e = p * \theta_m} \longrightarrow \quad \underline{\underline{مهم}}$$

$$\therefore w_e = p \, w_m$$

- When $p = 1 \implies \theta_e = \theta_m \quad ; \quad w_e = w_m$
- When $p = 2 \implies \theta_e = 2\theta_m \quad ; \quad w_e = 2w_m$

Relation between f_e & n_m

$\theta_e = p\,\theta_m$

$\therefore \dfrac{d\theta_e}{dt} = p\,\dfrac{d\theta_m}{dt}$

$\omega_e = p\,\omega_m$

$\therefore 2\pi f_e = p \times 2\pi f_m$

$\therefore f_e = p\,f_m$

But $f_m = \dfrac{n}{60}$

where n : Number of reVolutions per minute (rpm)
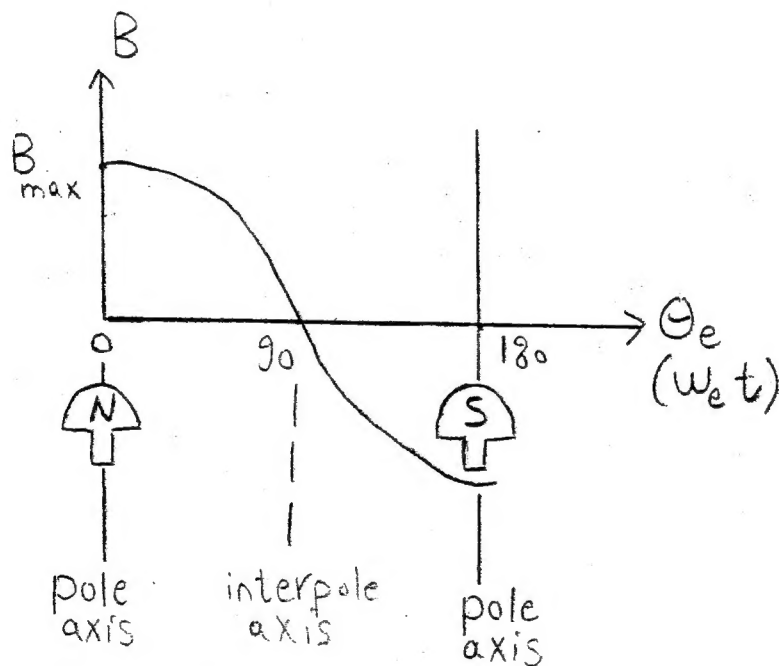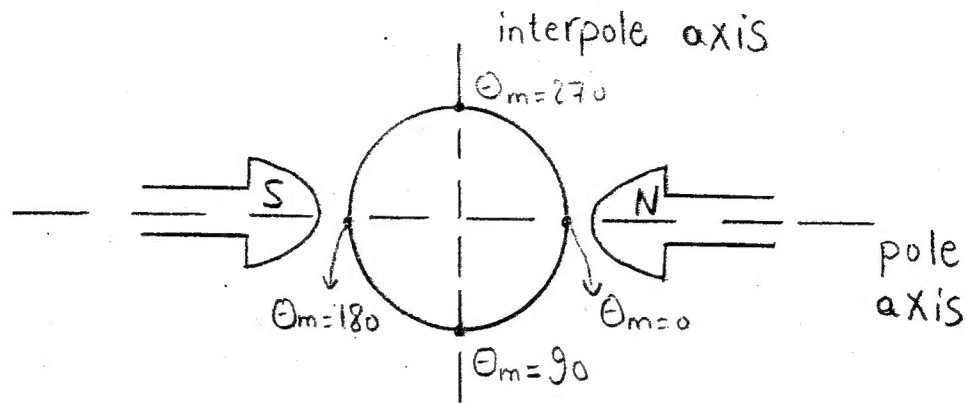
$$\therefore f_e = \dfrac{pn}{60}$$

f_e : electrical frequency (Hz)

p : Number of pole pairs

n : Mechanical speed of rotor in rpm

S'

interpole axis

$\Theta_{m=270}$

S   N

$\Theta_{m=180}$ $\Theta_{m=0}$

pole axis

$\Theta_{m=90}$

B

B_{max}

O   90   180 Θ_e ($\omega_e t$)

N   S

pole axis   interpole axis   pole axis

$$B = B_{max} \cos(\omega_e t)$$

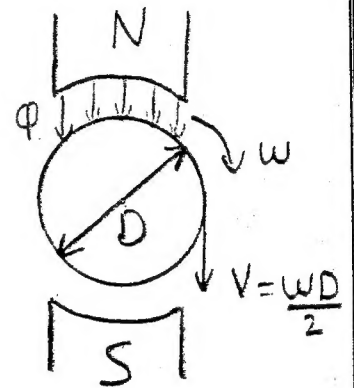This means that the Flux varies sinusoidal

$\overbrace{\text{E.M.F equation in DC Machines}}$ "proof"

$$e_c = B L V$$

Where

- $e_c \rightarrow$ Induced emf per Conductor
- $B \rightarrow$ Flux denisty $= \dfrac{\Phi}{A}$
- $L \rightarrow$ Conductor length
- $V \rightarrow$ linear speed
- $W \rightarrow$ Angular speed (ω_m)
- $n \rightarrow$ R.p.m
  (revolution per minute)

$$\boxed{\omega = \dfrac{2\pi n}{60}}$$

- $D \rightarrow$ Rotor diameter
- $\Phi \rightarrow$ Flux per pole

$$\Rightarrow B = \dfrac{\Phi}{A} = \dfrac{\Phi}{\dfrac{\pi D L}{2}} = \dfrac{2\Phi}{\pi D \ell} \quad , \quad V = \dfrac{\omega D}{2} = \dfrac{\pi D n}{60}$$

$$\therefore e_c = \dfrac{2\Phi}{\pi D L} \times L \times \dfrac{\pi D n}{60} = \dfrac{2 n \Phi}{60}$$

For Z Conductor $\Rightarrow \boxed{e_z = e_c \times Z}$

where e_z : Induced emf in all Conductors

$$E_a = \frac{e \cdot z}{a}$$

E_a = Induced emf in the armature

a = Number of parallel paths

$$\therefore E_a = \frac{2 n \varphi Z}{a \ast 60} = \frac{2 Z}{60 a} \, n \varphi$$

For (2p) poles $\implies$ $\boxed{E_a = \frac{2 P Z}{60 a} \, n \varphi}$

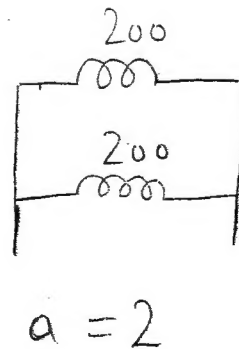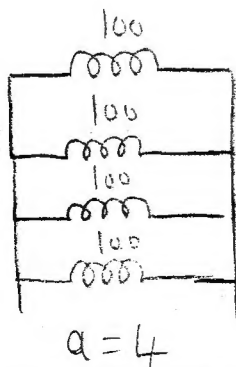$$\boxed{E_a = K n \varphi}$$ where $K = \frac{2 P Z}{60 a}$

\#

What are parallel paths (a) للفهم فقط

* If $Z = 400$ (total number of conductors = 400)

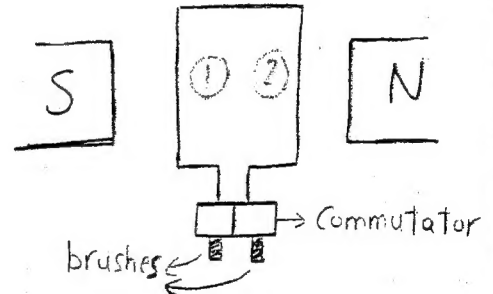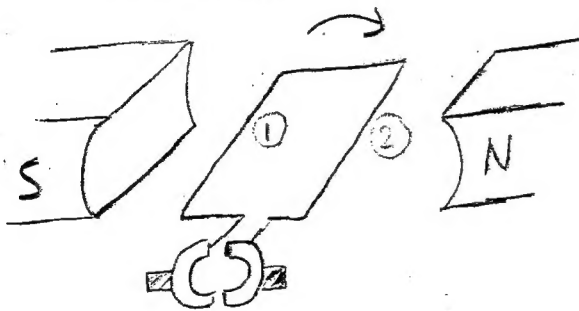Not all conductors are connected in series
To reduce voltage drop and losses

100
100
100
100

$a = 4$

200
200

$a = 2$

Dc machine can operate as
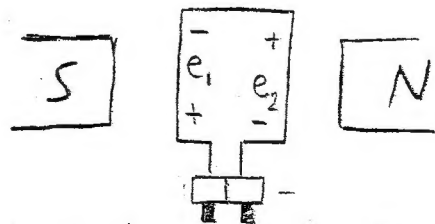1. Dc generator
2. Dc motor

[1] DC generator

Theory of operation

(a) The field current produces flux

(b) IF the rotor (armature coil) is externally rotated

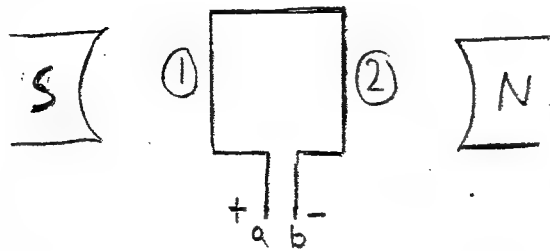(c) A voltage will be induced on both conductors (1,2)
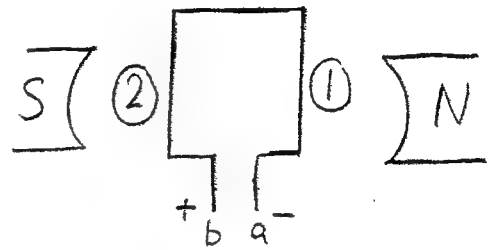
$$e_1 = BLV \qquad e_2 = BLV$$

$$e_{coil} = 2BLV$$

(d) The commutator converts Ac voltage into Dc.

Why do we use Commutator & brushes المفهوم فقط

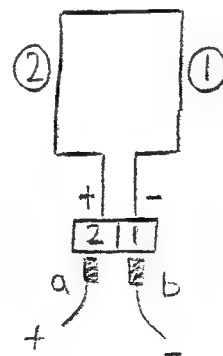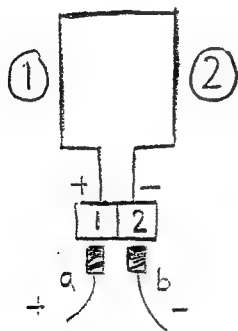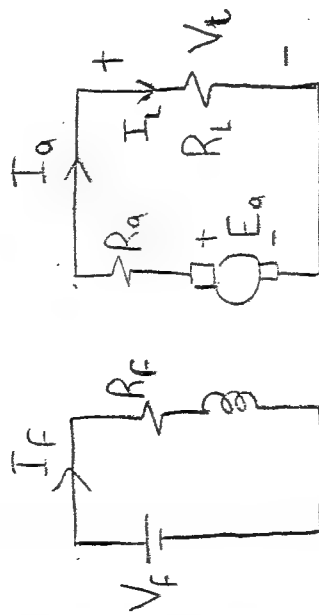| In First half Cycle of the Coil rotation	In Second half Cycle of the Coil rotation

The Voltage across the coil changes its polarity, So we use Commutator and brushes as a mechanical rectification to get Dc Voltage from the coil

* brush ⓐ is +Ve in both half cycles
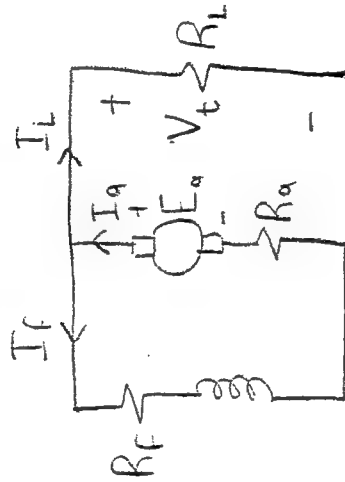brush ⓑ is -ve "   "   "   "

Types of Dc generators

I Separately excited
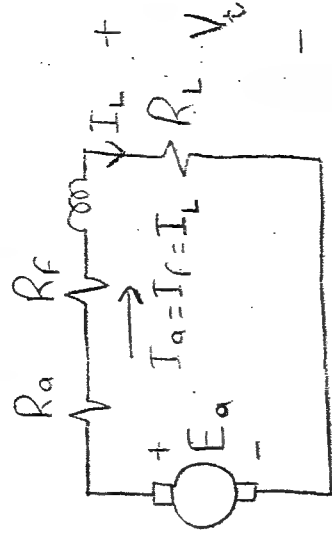

$$V_f = I_f R_f$$

$$E_a = V_t + I_a R_a$$

II Shunt

$$I_f = \frac{V_t}{R_f}$$

$$E_a = V_t + I_a R_a$$

III Series

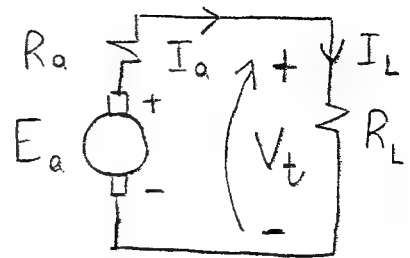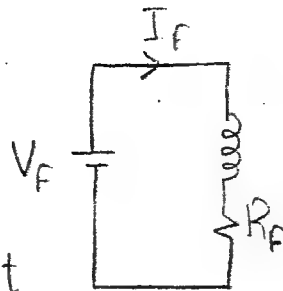$$E_a = V_t + I_a(R_a + R_f)$$

$$I_a = I_L = I_f$$

I. Separately excited DC generator

⟹ Field circuit

$$\boxed{V_F = I_F R_F}$$

* $I_F \rightarrow$ Field current
* $R_F \rightarrow$ Field resistance

⟹ Armature circuit

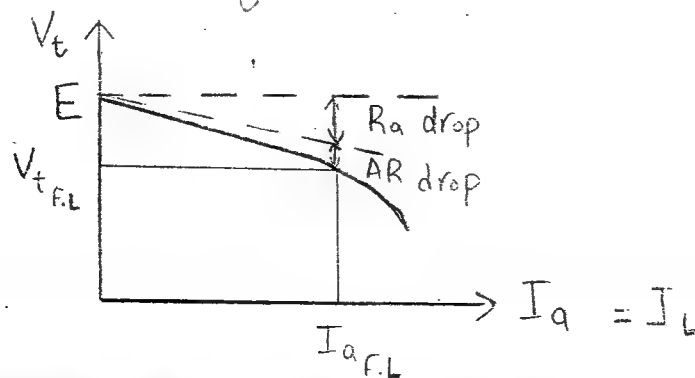$$\boxed{E_a = V_t + I_a R_a + (\text{Armature reaction drop})}$$

* $R_a \rightarrow$ Armature resistance
* $I_a \rightarrow$ Armature current
* $V_t \rightarrow$ Terminal voltage

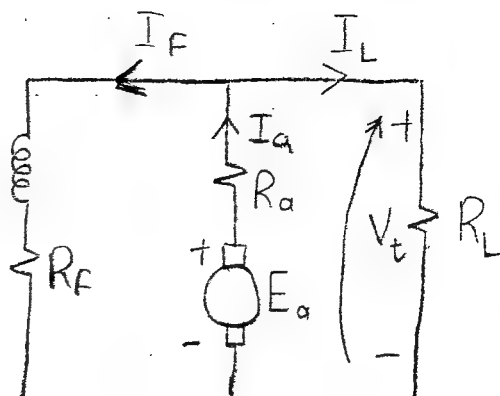IF (AR) is neglected $\Longrightarrow E_a = V_t + I_a R_a$

⟹ External characteristic of separately excited DC generator

Shunt DC generator

$$I_F = \frac{V_t}{R_F}$$

$$E_a = V_t + I_a R_a$$

The Voltage drop is due to

① R_a drop

② Armature reaction drop

③ Decrease in field current

as $I_F = \frac{V_t \downarrow}{R_F}$ (V_t decrease as I_L increases)

∴ $I_F \downarrow \rightarrow \Phi \downarrow \rightarrow (E_a = Kn\Phi) \downarrow \rightarrow V_t \downarrow$

That's why Shunt DC generator has external C/C's which is more drooping than that of separately excited (عشان ال sep.excited بيحصله اول نوعين من ال drop فقط)

External C/C's

$$I_{f.l} \qquad \rightarrow I_L$$

V_t, E_a — $I_a R_a$ — AR — Reduction in I_f
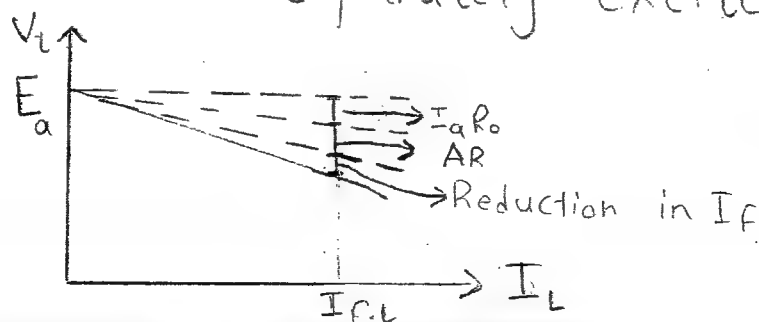
Series DC generator

$$I_a = I_F = I_L$$

$$E_a = V_t + I_a(R_a + R_F)$$

Ra   Rf

$$I_a = I_F = I_L$$

E_a R_L V_t

I_L
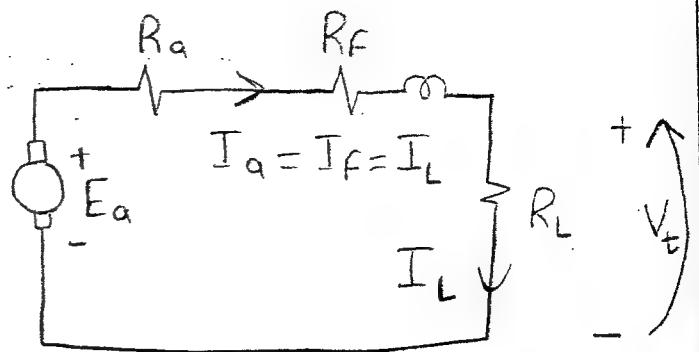
The voltage drop is due to

① $(I_a R_a + I_a R_F)$ drop

② AR drop.

(External C/C's)

V_t

magnetization curve

$\rightarrow I_a(R_a + R_F)$ drop

AR drop

external
C/C's

$\rightarrow I_L = I_a$

$I_{of.L}$
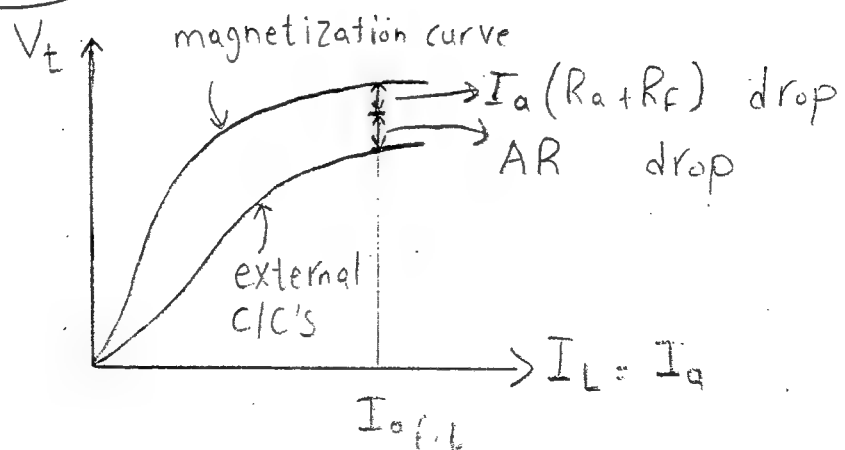
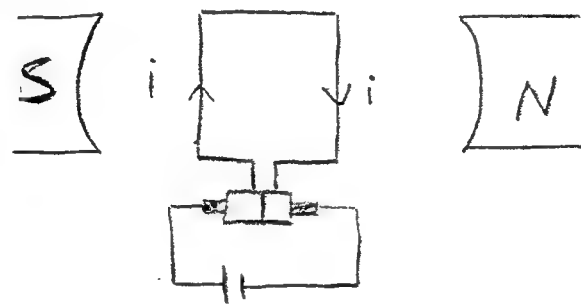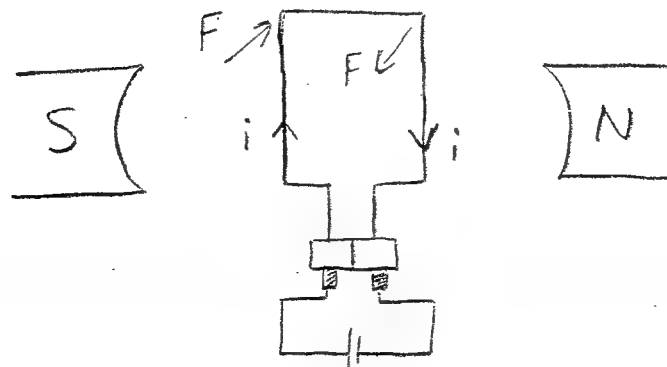## ② DC motor

Theory of operation

(a) The field current produces flux

(b) If the armature winding terminals are connected to an external DC source, then a current will flow in armature winding.

(c) Now both conductors (1,2) has a current i and placed in a magnetic field (B), so A force will be produced on both conductors but in opposite direction. $(F = BIL)$

(d) So, the coil starts to rotate with a torque $T = BILW$

(e) As the coil rotates in a magnetic field, so a back emf will be induced on the coil (as in generator)

(F) The commutator converts the torque into unidirectional torque

Types of DC motors

I Separately excited
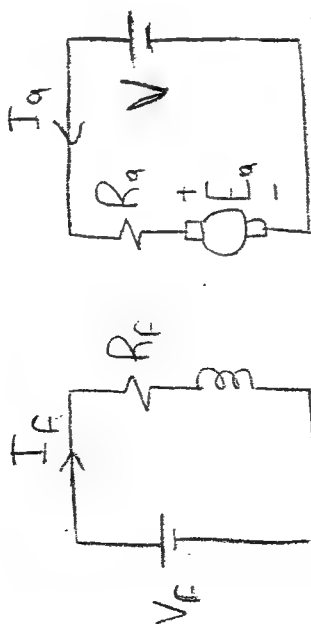
$$V_f = I_f R_f$$

$$E_a = V - I_a R_a$$

$$E_a = Kn\phi \Rightarrow E_a \propto n I_f$$

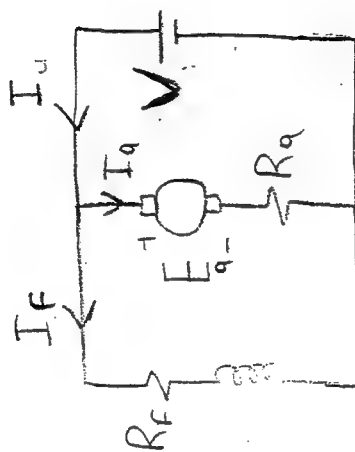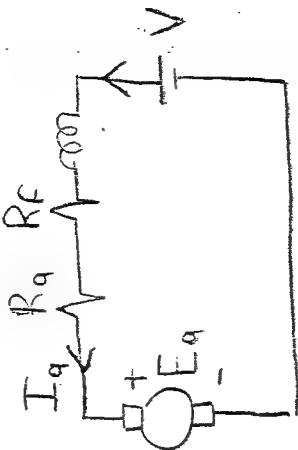$$T = K I_a \phi \Rightarrow T \propto I_a I_f$$

II Shunt

$$I_f = \frac{V}{R_f}$$

$$E_a = V - I_a R_a$$

$$E_a = Kn\phi \Rightarrow E_a \propto n I_f$$

$$T = K I_a \phi \Rightarrow T \propto I_a I_f$$

III Series

$$E_a = V - I_a(R_a + R_f)$$

$$E_a = Kn\phi \Rightarrow E_a \propto n I_a , \quad E_a \propto n I_f$$

$$T = K\phi I_a \Rightarrow T \propto I_a^2$$

power Flow in DC motor
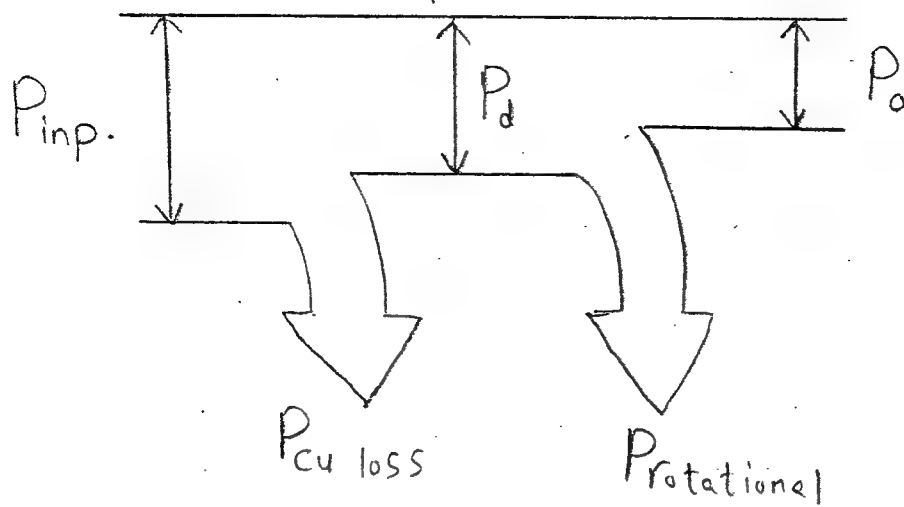
* $P_{inp} \equiv$ Input power $= V_s I_{inp.}$ → input current

* $P_{cu_{loss}} = I^2 R$ (depends on connection)

* $P_d \equiv$ developed power $= E_a I_a = T_d \omega_m$

* $P_r \equiv$ rotational loss

* $P_o \equiv$ output power $= T_{sh} * \omega_m$
  ↳ shaft torque

$$\eta = \frac{P_o}{P_{inp.}} = \frac{P_{inp} - \Sigma losses}{P_{in}}$$

* $P_o = P_d - P_{rotational}$ * $P_d = P_{in} - P_{cu_{loss}}$

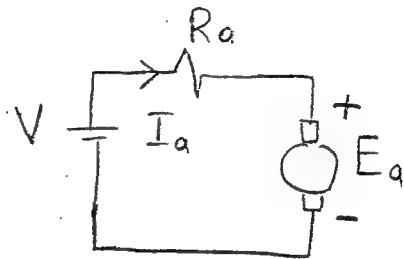## Role of back emf (E_a) in motors

E_a produces a current opposite to the supply current, so the armature current is limited within acceptable range

Starting of DC motors

$$\therefore V = E_a + I_a R_a$$

$$\therefore I_a = \frac{V - E_a}{R_a} \quad \text{but } E_a = K n \phi$$

But at starting $(n=0) \Rightarrow E_a = 0$

$$\therefore I_a \big|_{st.} = \frac{V - 0}{R_a} \uparrow\uparrow \text{ (very high)}$$

$\therefore$ The armature current is very high at starting; so we must use starters (starting resistors to reduce $I_a|_{st.}$)

11 page (13)

12
  (i) page (7,8)
  (ii) page (19)
  (iii) page (17)

13 * Different methods of excitation

  Separately   Self
  excited   excited
  generators   generators

                  Series   Shunt
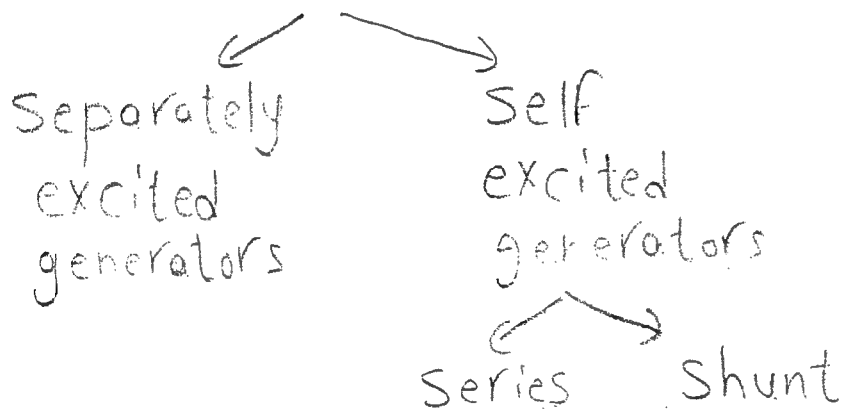
  * Characteristics → page (11)

  * Significance of back emf → page (19)

17 The armature of DC machine is
   laminated to reduce eddy current loss

(20)

(14) Series motor

$R_a = 0.5 \, \Omega$, $R_F = 1.5 \, \Omega$

$I_a = 20 \, A$ when $n = 1200 \, rpm$

$V = 220 \, V$, $P_{rotational} = 150 \, W$

Find P_o , η

(Solution)

$E_a = V - I_a (R_a + R_F)$

$E_a = 220 - 20(0.5 + 1.5)$

$\therefore E_a = 180 \, V$
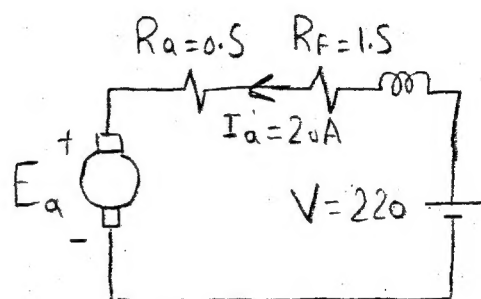
$\implies P_o = P_d - P_{rot.}$; $P_d = E_a I_a = 3600 \, W$

$\therefore P_o = 3600 - 150$

$\boxed{P_o = 3450 \, W}$

$\implies P_i = V * I_a = 4400$

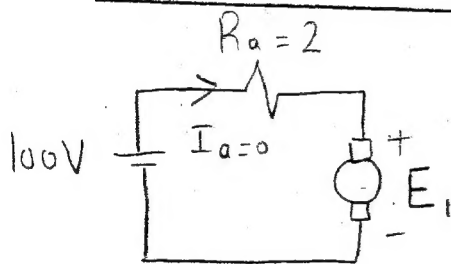$\implies \eta = \dfrac{P_o}{P_i} = \dfrac{3450}{4400} = 78.4\%$

$\boxed{\eta = 78.4\%}$

15 . Dc motor (Assume separately excited)

- **at No load** · $V = 100V$, $n = 1200$ rpm

- $R_a = 2\Omega$

- **Find** T, I_a if $V = 220V$, $n = 1500$ rpm

- I_f is constant

(Solution)

Case ① $V = 100V$
$n_1 = 1200$ rpm
No load $(I_a = 0)$

$R_a = 2$

$100V \;\underline{}\; I_a = 0 \quad + E_1$

$$E_1 = 100V$$

$E_1 = Kn\Phi = K'n$

$100 = K' * 1200$

$$K' = 0.083$$

Case ② $V = 220V$
$n_2 = 1500$ rpm

$R_a = 2\Omega$

$220V \;\underline{}\; I_2 \quad + E_2$
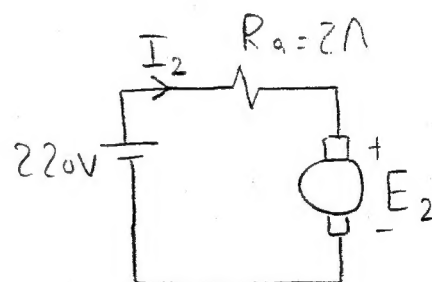
$\Rightarrow \dfrac{E_2}{E_1} = \dfrac{n_2}{n_1}$

$\dfrac{E_2}{100} = \dfrac{1500}{1200} \Rightarrow \boxed{E_2 = 125v}$

$\Rightarrow$ But $E_2 = 220 - I_2 * 2$

$$I_2 = 47.5A$$

$$T = K I_a \Phi = K' I_a = 3.96 \, N \cdot m$$

(16) • DC shunt motor

• Constant field (I_F = Const.)

• T $\propto$ n

• I_a = 30 A when n_1 = 750 rpm

• R_{series} = 10 Λ $\Rightarrow$ n_2 = ??

• R_a is neglected

Solution

Case (1) n_1 = 750 rpm
I_{a_1} = 30 A
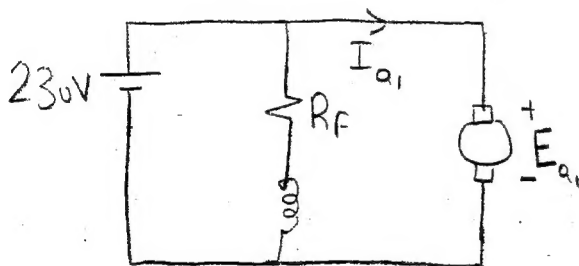
E_{a_1} = 230 V

Case (2) R_{series} = 10 Λ
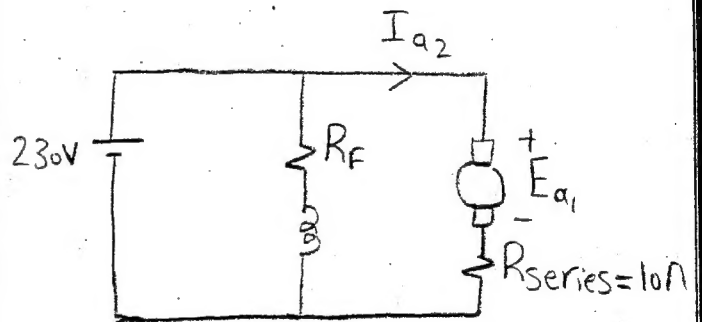
E_{a_2} = 230 - 10 I_{a_2}

$\Rightarrow$ But E $\propto$ nϕ $\overset{\text{Constant}}{\Rightarrow}$ E $\propto$ n

$$\therefore \frac{E_2}{E_1} = \frac{n_2}{n_1}$$

$$\frac{230 - 10 I_2}{230} = \frac{n_2}{750}$$

$0.306 \, N_2 + 10 \, I_2 = 230 \quad \longrightarrow \quad \text{①}$

$\Longrightarrow$ But $\quad T \propto n \; (\text{given})$

$\qquad T \propto \underset{\underset{\text{const.}}{\smile}}{\phi} I_a \implies T \propto I_a$

$\therefore \quad \dfrac{T_2}{T_1} = \dfrac{n_2}{n_1} = \dfrac{I_2}{I_1}$

$\therefore \quad \dfrac{n_2}{750} = \dfrac{I_2}{30}$

$\therefore \quad n_2 = 25 \, I_2 \quad \longrightarrow \quad \text{②}$

Solving ①, ② we get

$\qquad I_{a_2} = 13 \, A$

$\qquad n_2 = 325.7 \; rpm$